RISK ASSESSMENT OF CARBON FIBER COMPOSITE IN SURFACE TRANSPORTATION

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SUMMARY

The vulnerability of surface transportation to airborne carbon fibers and the national risk associated with the potential use of carbon fibers in the surface transportation system have been evaluated. Airborne carbon fibers may cause failure rates in surface transportation of less than one per year by 1995. The national risk resulting from the use of carbon fibers in the surface transportation system is projected to be an annual dollar loss on the order of $6,000.

INTRODUCTION

This report describes the status of the Department of Transportation Carbon Fiber Project which addresses the surface transportation portion of the coordinated Federal Government Carbon Fiber Action Plan presented in reference 1.

The DOT responsibilities are to assess the vulnerability of surface transportation to airborne carbon fibers and to assess the national risk due to carbon fibers released from surface transportation.

The project was divided into the following five tasks:

(1) To estimate the quantities of carbon fiber that will be used in the surface transportation system by 1995.

(2) To estimate the frequency and location of surface transportation system fire incidents.

(3) To estimate through laboratory tests the size and quantity of carbon fibers released by surface transportation fires.

(4) To estimate the vulnerability of the surface transportation system to airborne carbon fibers.

(5) To estimate the national risk from carbon fibers released in surface transportation incidents.

CARBON FIBER COMPOSITE USAGE

An estimate of the expected carbon fiber quantity and matrix composition in surface transportation was developed by DOT from a review of the existing literature, the Department of Commerce survey conducted in 1979 (presented in a preceding paper by Donald Parsons reference 2) and several independent inquiries to carbon fiber suppliers and users. This effort further established that the only prospective use of carbon fibers in the transportation system would be in automobiles, light trucks and heavy trucks. The DOT estimates place the total carbon fiber usage in surface transportation in 1995 at less than $5X10^7$ kg. The estimate DOT chose for its risk assessment was 2 kg in cars and light trucks and 15 kg in heavy trucks. Table 1 shows the actual DOT usage estimates and the expected matrix composition.

TRANSPORTATION FIRES

The exposure of carbon fiber composite materials to a severe fire is the principal mechanism for the release of carbon fibers. Table 2 shows a summary of surface transportation vehicle fires estimated by the U.S. Fire Administration (USFA) and a projection of total vehicle fires estimated by the National Fire Protection Association (NFPA). As stated previously, nearly all carbon fiber materials used in surface transportation will be found in cars and trucks. Therefore, car and truck fires are of principal concern in a study of potential carbon fiber release incidents.

The fire data inputs needed for the risk assessment consist of an estimate of the frequency and geographic location of the fire and portion of the vehicle involved. Fire frequency can be found in Table 2 but the above data sources have little information on geographic location.

The Highway Safety Research Institute at the University of Michigan has collected information from fire department records on automobile fires in the state of Michigan for the two year period from 1976-1977. This data is collected by county and it was possible to establish a correlation between the annual automobile fires per county and county population. The correlation (a correlation coefficient of 0.97) indicated that the urban car is more susceptible to fire as most automobile fires occur in urban areas where the vehicle population density is highest.

The other details of the automobile fire scenario which are important to fiber release are the severity of the fire and its location on the vehicle. The fire location on the vehicle was important to determine which of the composite materials were exposed to the fire. The vehicle fires were classified by one of the following scenarios: engine small, engine severe, passenger compartment small, passenger compartment severe and total conflagration. Severe fires were defined as the only fires that will release carbon fibers. Since no carbon fibers are expected to be used in the passenger compartment, only severe engine fires and total vehicle conflagration fires will release fibers. Roughly one-third of the car and truck fires fall into these two release scenarios. This estimate is based on an analysis of the passenger vehicle dollar loss statistics for fires and is published by the California State Fire Marshall.

LABORATORY TESTS

All the laboratory and field test data available for the release by fire of carbon fibers from composite samples were on aerospace-grade, epoxy based materials, usually with post-fire impact or explosion. It was felt that this data was not an accurate representation of the fiber release expected from automotive-grade composite. Automotive composites are expected to be based on a matrix of vinyl ester or polyester and glass fibers blended with carbon fibers.

DOT developed a series of laboratory tests to measure carbon fiber release from automotive-type composites. The tests were designed to evaluate carbon fiber release under conditions which simulated automobile fires, namely high and low radiant heat flux with an 1800°C propane/air flame, fuel rich or fuel lean. The burning time was 10 minutes and there was no post-fire impact or explosion. Prior to the execution of the program by NASA-Ames and its contractor, Scientific Services, Inc., users and suppliers of the carbon fiber materials were asked to review and comment on the test program.

The results of this test program are briefly summarized in Table 3. The quantities of carbon fiber released were found to be sensitive to the test condition but not to the matrix resin. Depending on the test conditions, the basic results from this test program were an average carbon fiber release over the range from 0.003 percent to 0.06 percent of the composite carbon fiber weight. Ninety-nine percent of all carbon fibers released were less than three millimeters in length. Fibers of this length in the quantities released from the test are unlikely to cause electrical failures in any individual incident.

VULNERABILITY OF SURFACE TRANSPORTATION

Surface transportation systems have been designed to operate reliably and safely in an environment of dust, oil, salt spray and vandalism. These system requirements produce a system design which is not easily affected by a carbon fiber hazard. From the above analysis of the Michigan data, it was determined that most of the carbon fiber exposure will be in the vicinity of the urban roadway system. Since very little of this urban roadway system interfaces with the waterway transportation system, the vulnerability of water transportation was not evaluated beyond a brief qualitative determination that it would be relatively invulnerable to the few carbon fibers to which it would be exposed. The remaining modes bore the brunt of the exposure and were thoroughly evaluated.

The method used to estimate the vulnerability of a surface transportation system was to divide the system into subsystems and, if necessary, components to a point where the vulnerability of the subsystem or component could be estimated from vulnerability data published by NASA and DOD. The effects of the subsystem failure are then classified as safety, performance or convenience failures. A safety failure occurs when there is a significant loss of system safety; a performance failure occurs when there is a significant loss in system performance; and a convenience failure occurs when there is a significant loss in the perceived comfort or convenience by the passengers or crew. This analysis as applied to the passenger car is seen in Table 4. In the vulnerability column, V indicates a vulnerability less than 10^8 fiber seconds/meter^3; P means that the equipment is sealed against fiber penetration; and C means that the current and voltage ranges are insensitive to carbon fibers. For example, the alternator will burn out any carbon fibers which penetrate it, the voltage regulator is potted in plastic, but carbon fibers can interface with the operation of the radio. Table 4 shows that only radios may be vulnerable to carbon fibers. Tests have shown that an automobile radio has a vulnerability greater than 10^8 fiber seconds/meter^3. The passenger car, thus, is effectively not vulnerable.

Similar analyses have shown that both the truck and the bus are also not vulnerable. Traffic signal systems are housed in sealed enclosures which will exclude carbon fibers so that they too are not vulnerable. The net result is that the highway system is not vulnerable to airborne carbon fibers.

Electrified rail systems were analyzed by dividing them into carborne, wayside, electric substation and signal subsystems. The result of this analysis is shown in Table 5. These vulnerabilities, with the exception of the signal system, all represent system failures. Most of the failures are monetary and are likely to require no maintenance or repair, e.g., a flashover at a third-rail insulator. The vulnerability of the vehicle is shown for both a single car and a six-car train. The vulnerability of the six-car train assumes that the traction motors must fail on more than three cars for the train to fail. This is a reasonable assumption since the performance of a train is not significantly affected until more than half its cars lose their traction motors. It is, in fact, common for transit systems to have failed cars in their trains.

RISK ASSESSMENT

A typical surface transportation release incident can be characterized as a release of 20 grams of single fibers, less than 3 mm long; most of the fibers fall out within a kilometer of the source, and the incident frequency is correlated with population. It is estimated that there will be 100,000 such incidents a year. Preliminary calculations show that the probability that there is any damage from an individual incident is very low. As discussed in reference 3, the case where there are a large number of incidents with a low probability of damage by an individual incident is best modeled analytically by Poisson statistics.

The national risk due to fibers released by surface transportation was computed by the NASA Langley Research Center contractor Arthur D. Little Inc. under a reimbursable agreement from DOT to NASA. A brief review of their method is as follows:

The number of release incidents and number of carbon fibers released each year is estimated for each of 3,000 counties in the U.S.

The number of equipments, along with their associated vulnerabilities and failure costs, is tabulated for these counties.

The losses for the individual counties are then calculated and summed to determine the national risk.

The result of this calculation was a projected annual national dollar loss, associated with the use of carbon fibers in surface transportation, on the order of $6,000 per year.

CONCLUSIONS

The vulnerability of surface transportation to airborne carbon fibers is very low. The risk of failure is less than one a year at the carbon fiber hazard level predicted for the year 1995. Similarly, the national risk due to this hazard is very low. The annual dollar or loss estimate is on the order of $6,000 a year. Because of this small vulnerability and risk, the DOT carbon fiber program will conclude early in FY 80.

REFERENCES

1. Carbon Fiber Study. NASA Technical Memorandum 78718, May, 1978.

2. Parsons, D.: Carbon Fiber Domestic Data Base - Market Analysis, Production Capacity, and Cost Projections. Department of Commerce presentation at Conference on the Assessment of Carbon Fiber Electrical Effects (Hampton, Va.) Dec. 4-5, 1979.

3. Fiksel, J.; Rosenfield, D.; and Kalelkar, A.: Assessement of Risk Due to the Use of Carbon Fiber Composites in Commercial and General Aviation. Assessment of Carbon Fiber Electrical Effects, NASA CP-2119, 1980. (Paper 9 of this compilation.)

TABLE 1

DEPARTMENT OF TRANSPORTATION CF USAGE ESTIMATES

Year	Average CF/Auto (KG)	Average CF/ Heavy Truck (KG)
1990	0.5	1.0
1995	2.0	15.0

PROJECTED MATRIX COMPOSITION

RESIN	TYPE
Polyester	Graphite/Glass Hybird
Vinyl ester	Graphite/Glass Hybird

TABLE 2

TRANSPORTATION FIRES* (1977 - USFA)	
PASSENGER VEHICLES	325,000
FREIGHT ROAD VEHICLES	58,000
RAIL TRANS. VEHICLES	2,800
WATER TRANS. VESSEL	1,850
AIR TRANS. VEHICLE	550
HEAVY EQUIPMENT	7,000
SPECIAL VEHICLES	2,700
OTHER MOBILE PROPERTY	100
UNDETERMINED	62,000
TOTAL	460,000
NFPA EST.** TOTAL	490,000

*EST. BASED ON 26% SAMPLE OF U.S. POP. (8 STATES)

**BASED ON DATA FROM 4% OF FIRE DEPTS. (IN 50 STATES)

TABLE 3

TEST RESULTS

	HIGH RADIANT, FUEL LEAN	LOW RADIANT, FUEL RICH
AVERAGE PERCENT RELEASED	.003%	.06%
AVERAGE MEDIAN FIBER LENGTH	0.1 MM	0.9 MM

TABLE 4

PASSENGER CAR ELECTRICAL SYSTEMS

SUBSYSTEM/COMPONENT	VULNERABILITY	EFFECT
ENGINE:		
IGNITION	P	PERFORMANCE
ALTERNATOR	C	CONVENIENCE
VOLTAGE REGULATOR	P	CONVENIENCE
BATTERY	C	PERFORMANCE
STARTER	C	PERFORMANCE
CHASSIS:		
HEATER	C	CONVENIENCE
WINDOW DEFOGGER	C	CONVENIENCE
WIPER/WASHER	P	SAFETY
FUEL:		
PUMP	P	PERFORMANCE
EMISSION CONTROLS	P	PERFORMANCE
INJECTION	P	PERFORMANCE
LIGHTING:		
HEADLIGHT	C	PERFORMANCE
TAIL LIGHT	C	SAFETY
BRAKE	C	SAFETY
TURN	C	SAFETY
INTERIOR	P	CONVENIENCE
ACCESSORIES:		
CLOCK	P	CONVENIENCE
ENTERTAINMENT - RADIO	V	CONVENIENCE
CB RADIO	V	CONVENIENCE
DIGITAL INST.	P	CONVENIENCE

V - POTENTIALLY VULNERABLE.

P - PROTECTED FROM PENETRATION OF CARBON FIBER.

C - CURRENT OR VOLTAGE IN A RANGE NOT SENSITIVE TO CARBON FIBER.

TABLE 5

VULNERABILITY OF AN ELECTRIFIED RAIL SYSTEM

VEHICLE	FIBER SEC/METER^3
SINGLE CAR	1.5×10^5
6 CAR TRAIN	1.5×10^9
WAYSIDE POWER	1.8×10^6
SUBSTATION	3.5×10^8
SIGNAL SYSTEM	6×10^9